Workshop on the Science of Fusion ignition on NIF
May 22 – May 24, 2012

http://lasers.llnl.gov/workshops/science_of_ignition/

Panel 5: HED Materials Cross-cut

May 24, 2012: Final Panel Outbriefs Plenary Session

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HED Materials - Crosscut
Final Panel Outbrief

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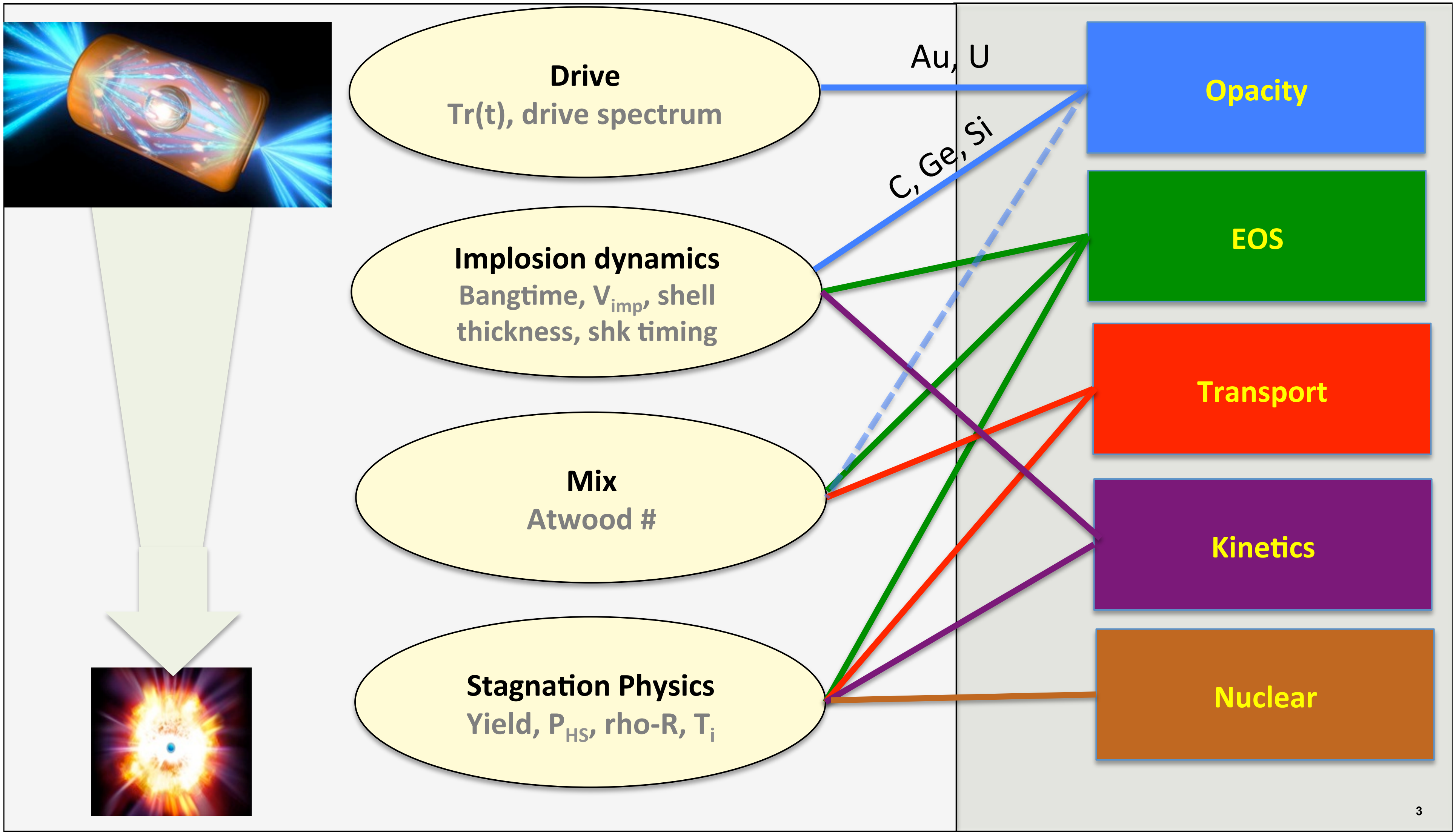
We will go through physical models in the codes, discuss their uncertainty, and what physics is missing

Implosion Performance and NIC Observables **Physical models**



HED Materials-Opacity

Underlying physics to be addressed

Physics process: Radiation absorption and emission

Approximations:

- Ionization potential depression
- Spectral line profiles
- Spectral complexity forces approximate electronic energy level descriptions
- NLTE requires kinetic approach, presently incompatible with hydro simulations
- Radiation absorption at ablation front is inherently nLTE because the incident nLTE spectrum is further distorted as the ablation plasma filters incident radiation. But even LTE transmission experiments in the T>200 eV regime are non-existent.

Learned from Recent Experiments

• Opacity & EOS models have a large influence on predicted ablator response to drive radiation, with large consequences for the implosion performance

Recent experimental results

- Discrepancies between predictions and preliminary transmission measurements (Si & Ge at Omega, Fe at Z)
- Al ionization potential depression measurements at LCLS indicate widely used Stewart Pyatt model is inadequate
- Models predictions of Au M-band emission have rarely been accurate in regimes without existing data (NIF hohlraums?)

Research Directions

Experimental platforms:

- Need continuity for full development and exploitation
- Need 2 platforms for each high impact measurement

Experiments Should…

- Focus on strategic materials and regimes identified through thoughtful sensitivity studies
- Break the problem down to the most basic level (address microphysics in opacity models where possible)

Theory should…

- Include benchmarked microphysics (e.g., line profiles or IPD)
- Strive for self consistent EOS and opacities

Code development should…

- Use approximations to mimic benchmarked detailed models
- Reflect reality while balancing simplicity & sophistication

Outcome and Potential Impact

Outcome: Stable and reproducible LTE and nLTE measurements of κ_ν, ε_ν will validate opacity codes & lead to QMU for ignition sims.

Impacts:

• Constrain integrated sims & improve predictive power

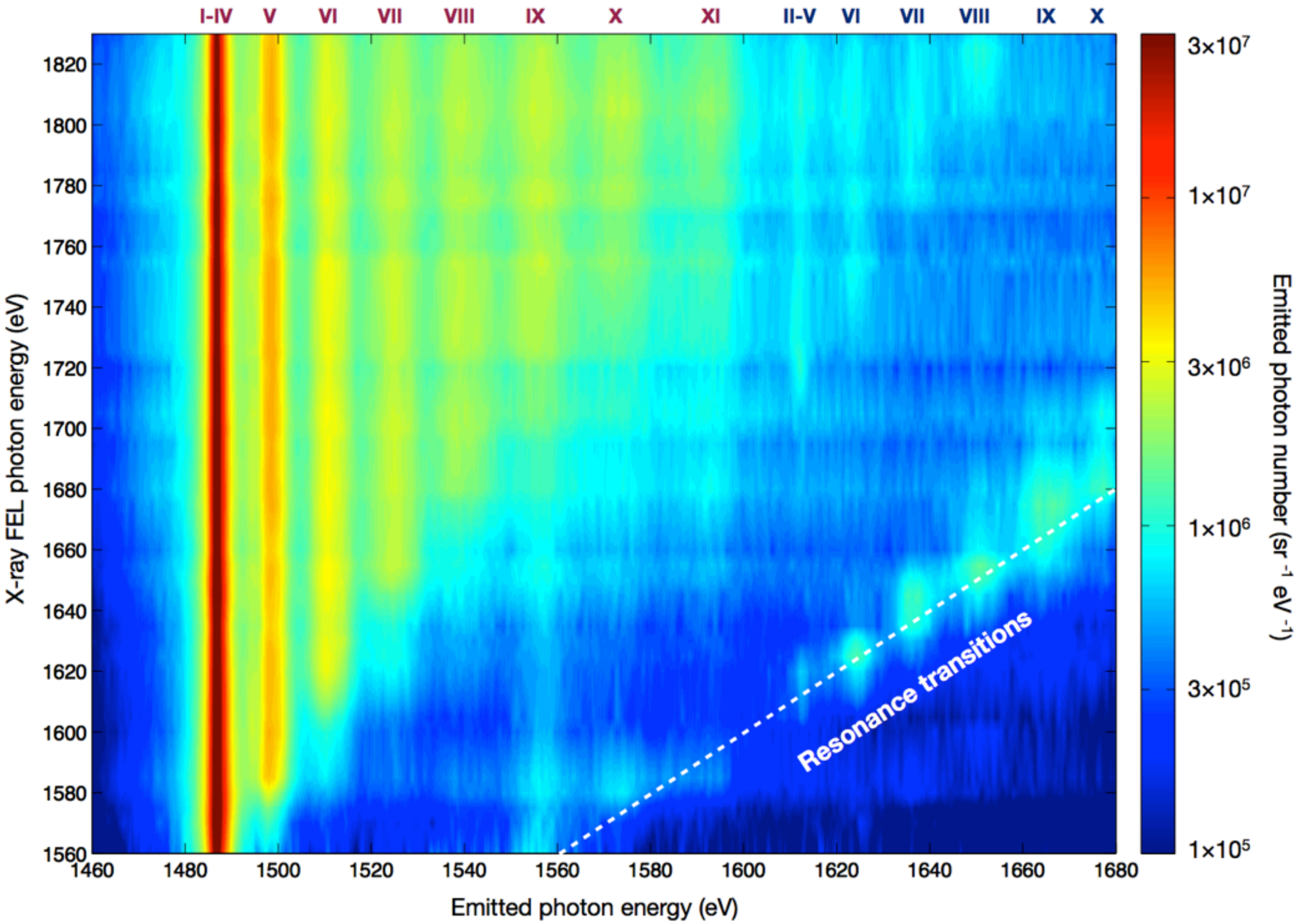
• Improve capsule material selection & design adaptability

• Spectrometers+Tracers: improve diagnosis wall-to-core

  • Hot-spot spectra (tracers+mix) diagnose fuel conditions

Long term benefits to all HEDP including astrophysics, stewardship and basic science as well as ICF

K-shell spectroscopy of Hot Dense Aluminium



S.M. Vinko et al, Nature, 482, 59-62 (2012)

O. Ciricosta et al, submitted to PRL

HED Materials – Equation of State

Underlying physics to be addressed

- EOS controls fuel and ablator properties throughout implosion, but models are constrained over a very limited range.
- How compressible (thermo derivatives) is hydrogen (ablator) along ignition path from cryo to 1.5 Kg/cc (~100g/cc).
- What is the physics (ionization, compressibility, sound speed) of ablator at and beyond ablation front
- Behavior of strong shocks in the hotspot

Learned from Recent Experiments

- Sensitivity to EOS affects many of the unresolved differences between experiment and simulations
  - Low implosion velocity, thick ablator, drive multipliers, low hot spot pressure and rho-R
- LEH closure may be related to Au EOS
- High hotspot entropy (gas shocks, 5^{th} shock)
- Oscillation in ablator thickness (sound speed in ablator)

Research Directions

•Experiments and ab-initio calculations to extend, DT and ablator (ch, Be, B4C, C…) EOS on and off Hugoniot (release paths, multiple shock paths, high convergence)to peak pressures (many Gbar) to peak density >1Kg/cc (DT) and >100g/cc (ablator) does matter reach a Thomas Fermi limit?

•Strong shocks in the gas (radiative waves, thermal conduction outrunning compression)

•Path dependence of ch and DT compressibility/entropy (viscosity)

•Ultra-high P mixtures (phase separation)

•Wave propagation through stratified matter

•Sound speed in shell in flight (1-10 +g/cc) to ensure pulseshape is tuned with reverberations

•How does fuel boil off from dense fuel to hotspot

•What physics sets the shape of leading density profile

•Novel EOS measurements (e.g. isochoric heating) for NIC-relevant regimes:
- high T, low ρ NLTE ablator blow-off region
- high ρ, lowish T ablator and DT

•Consistent NLTE EOS and opacity
•Unknowns – mixing, conductivity, viscosity…

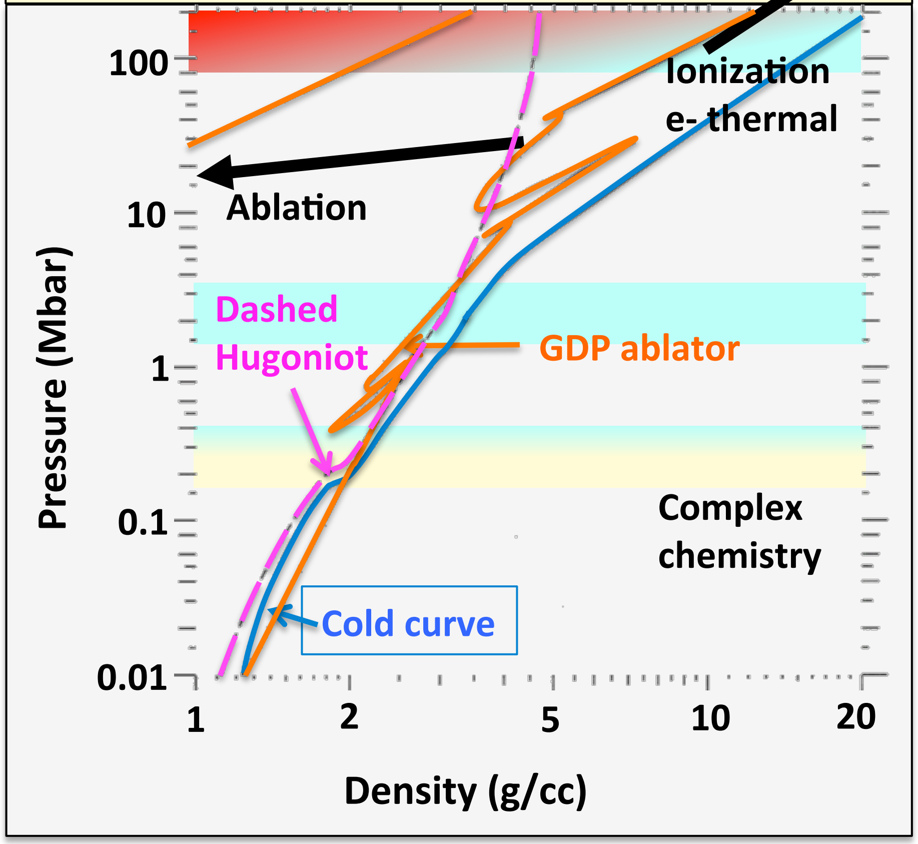
Outcome and Potential Impact

- Improved, validated EOS can enable more predictive NIC simulations
  - Correct modeling of shock timings, density, entropy, release, with realistic drive;
  - Predictive model for hotspot size, density, temp
  - Predictive model for hotspot and shell entropy
  - Predictive model for shell compression
  - Predictive model for implosion density profile
  - Predictive compressive energy of shell
  - Predictive model for ablation and implosion velocity

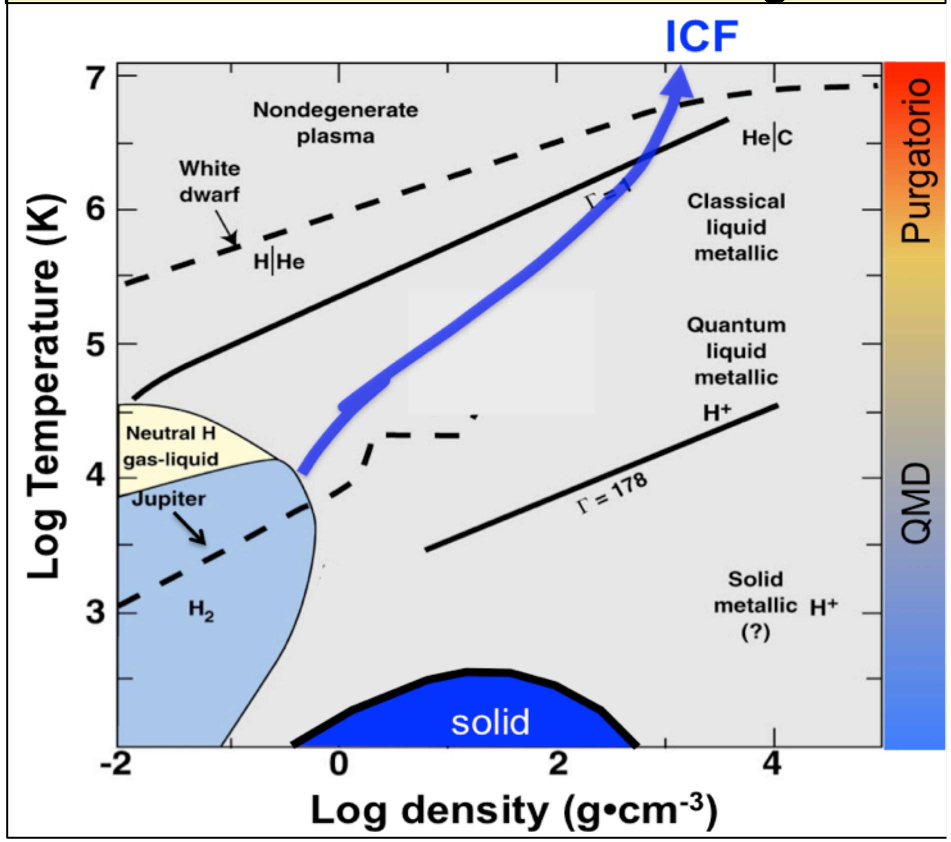
Self consistent and validated EOS/Opacity may lead to predictive hohlraum performance

ICF requires knowledge of the hohlraum, ablator and fuel EOS over a broad range of conditions

Trajectory for glow discharge polymer (GDP), $CH_{1.3}$ ablator in ICF implosion



We need to know DT to 1.5 Kg/cc



Other ablator candidates include diamond, Be, B4C, Al

HED Materials Cross-Cut

Nuclear Physics

Underlying physics to be addressed

- Nuclear physics underpinning prompt and radiochemical diagnostics
  - Prompt
    - Nuclear reactions with prompt γ-ray
    - Reactions affecting neutron spectrum
  - Radiochemistry
    - Nuclear reactions on unstable isotopes

Learned from Recent Experiments

- Neutron spectrum from t(t,2n)α has strong energy dependence?
- Ytt/Ydt ratios forced relook at multiple neutron scattering and deuteron breakup at high energies
- Recent SRC data demonstrate proof of principle

Research Directions

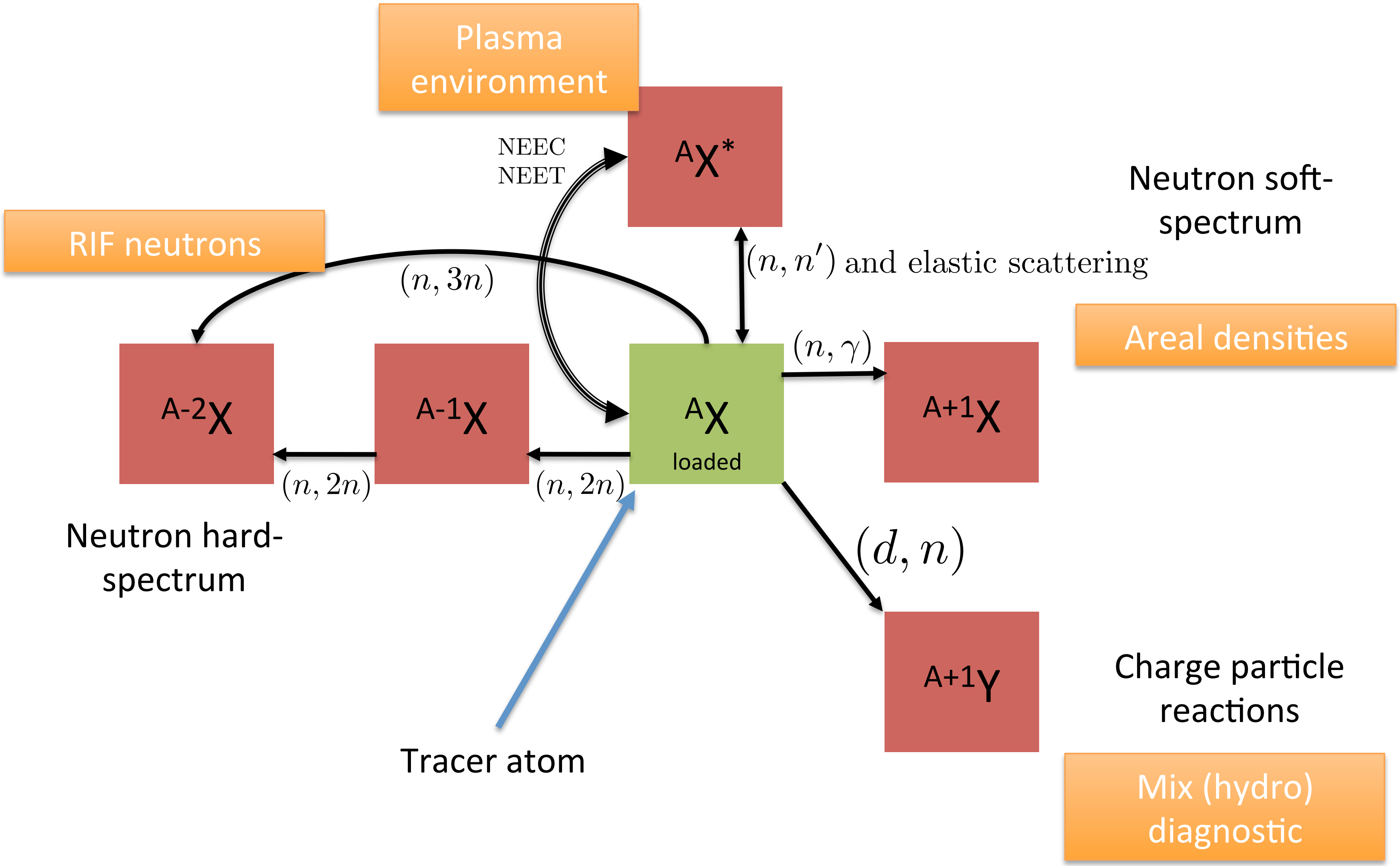
- Accelerator experiments
  - Inverse kinematics/surrogate
  - Measure reactions on unstable nuclei
- Theoretical fronts
  - Light-nuclei Reactions from First Principles
  - High-Performance computing
- Nuclear Diagnostics for HED Science
  - Investigate novel diagnostics and *in-situ* detectors
- The Interplay between Nuclear and Plasma Physics

Outcome and Potential Impact

- Provides window into ICF environments
- Constrains physics models
- Foundation for performing future nuclear science experiments at the NIF

HED Materials Cross-Cut

Nuclear Physics and ICF Diagnostics



Theory/modeling

HED Materials: Transport

MD studies of hot spot physics

Underlying physics to be addressed

- Distribution function – is it Maxwellian?
- Relaxation rates (ion thermalization, electron-ion), do we model them correctly?
- Alpha stopping powers

Learned from Recent Experiments

- NIC hot spot conditions (pressure, yield etc) not understood
- Anomalous OMEGA results

Research Directions

- What can be done to address the challenge?
  - Theory: Detailed MD simulations of the hot spot conditions and comparison with predictions from fluid codes for equivalent conditions

Outcome and Potential Impact

- Improved insights into hot spot physics
- Better understanding of conditions where fluid-description approximations break down

Experiment

HED Materials: Transport

Stopping power measurements

Underlying physics to be addressed

- Stopping power in the hot spot and cold fuel is key to understanding many parameters (yield, DSR etc)
- Very few experimental measurements of stopping power at relevant energies in plasma samples exist to compare with current models

Learned from Recent Experiments

- Stopping power well known in cold samples, very few experimental tests in plasma samples
- Ongoing GSI/Darmstadt University results, but still not quite relevant to fusion spot conditions

Research Directions

- What can be done to address the challenge?
  - Current GSI/Darmstadt University stopping power experiments should be supported in developing a robust experimental platform
  - A larger collaboration with the GSI/ Darmstadt University team should be developed to extend the measurements to other facilities (OMEGA, NIF)

Outcome and Potential Impact

- Validation of models and improved confidence in predictions

Experiment

HED Materials: Transport

Electron-ion equilibration

Underlying physics to be addressed

- Electron-ion energy exchange for two-temperature plasmas
- Are collective effects important?

Learned from Recent Experiments

- A few experiments suggest relaxation rates are lower than theoretical predictions

Research Directions

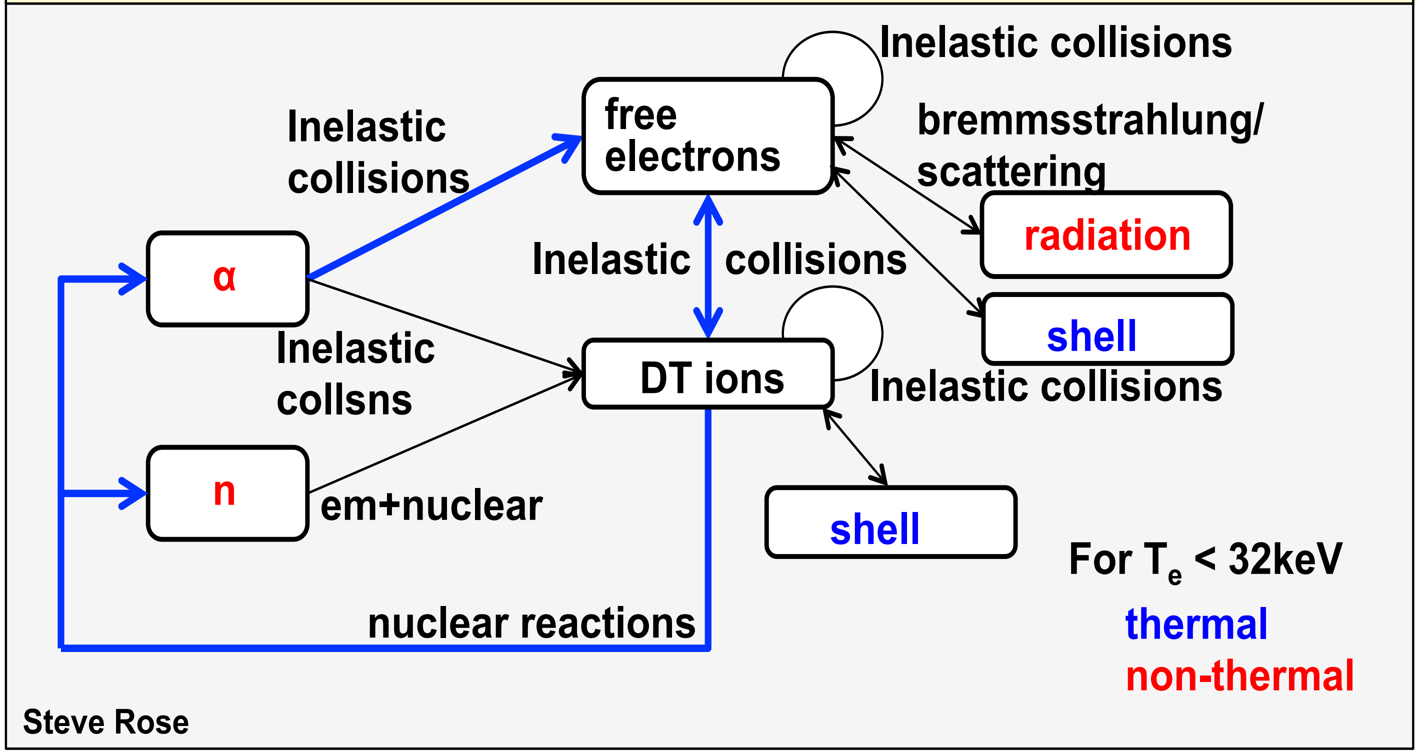
- What can be done to address the challenge?
  - Develop new platforms to create and probe two-temperature plasmas, both dense (strong coupling, degenerate) and low density (weak coupling)
  - Use x–ray Thomson scattering for dense samples, optical Thomson scattering for low density samples

Outcome and Potential Impact

- Improved understanding of electron-ion energy exchange, and improved assessment of consequences for hot spot physics

Energy transport in the hotspot

Time constants for transport of energy between "energy reservoirs" is not too different than fusion burn time



None of these rates are benchmarked at relevant conditions

HED Matter Cross-Cutting: Kinetics

Underlying physics to be addressed

- Breakdown of fluid approximation: occurs in high-temperature, low-density, and small spatial-scale regimes
- Potential influence of self-consistent electric fields on implosions
- These effects are currently neglected in mainline simulations which are based on fluid approximation

Learned from simulations and NIF/OMEGA experiments

- 14.7 MeV proton backlighting of direct-drive implosions on OMEGA showed ~GigaVolt/m (kV/μm) electric fields in agreement with predictions
- Multi-fluid simulations suggest species separation in shock front

Research Directions

- Complete Large Scale Plasma (LSP) multi-fluid and kinetic simulations of shock morphology and propagation
- Complete LSP simulations of exploding-pusher implosion experiments on OMEGA; plan experimental tests of kinetic effects
- Calculate with LSP particle albedo effect in Knudsen layer

Outcome and Potential Impact

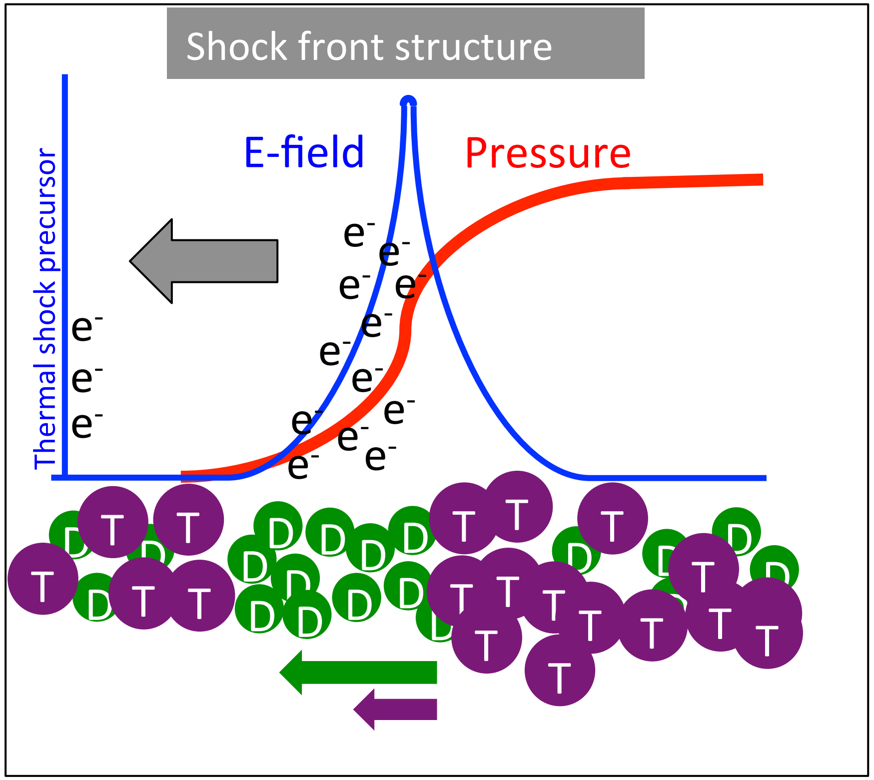
- Improved calculation of shock-flash timing and magnitude
- High-fidelity calculations of species stratification and diffusion

Transient passage of shock front in DT main fuel promotes interpenetration of D and T ions and frictional heating

SEPARATION

- Frictional drag between D and T fluids under action of *E*-field and pressure gradient at shock front promotes auxiliary heating

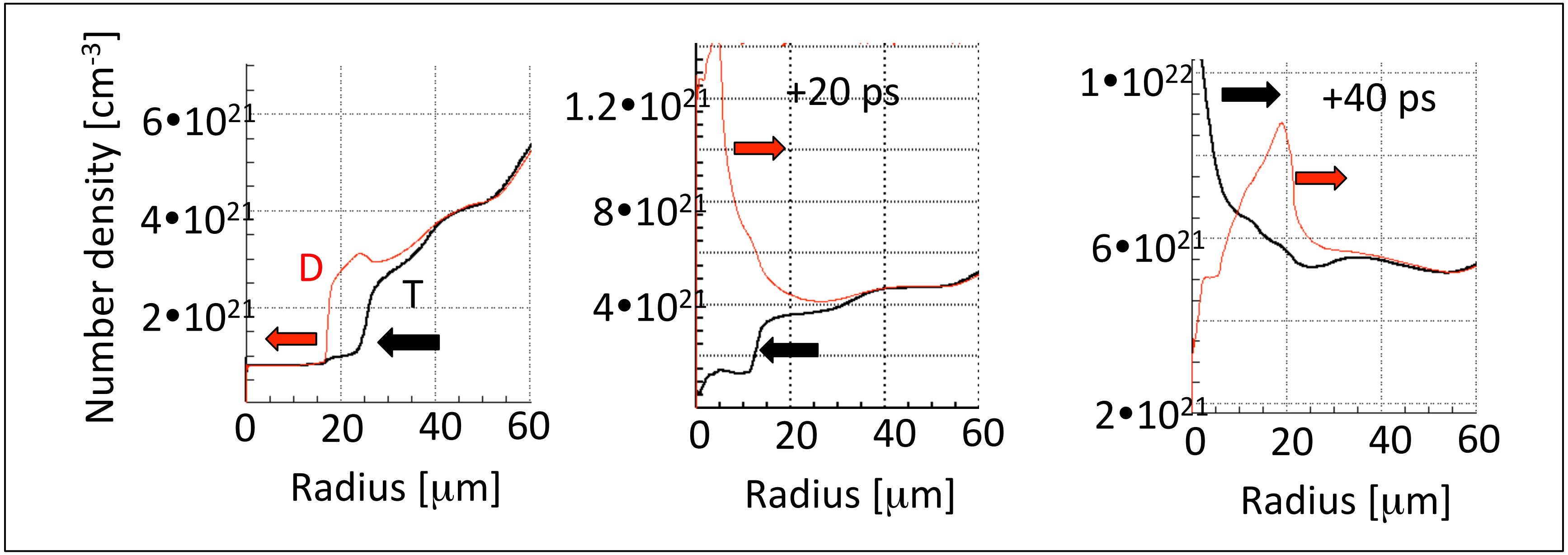
  - High e^- mobility leaves surplus ahead of shock, creating *E*-field
  - two-species effect: D moves ahead of T within shock front ($m_D < m_T$)
  - effect NOT in production codes
  - nonzero ionization states $(\bar{Z} \neq 0)$ magnify effect



Significant fuel species separation occurs before and after shock flash, according to multi-fluid LSP simulations

DT SEPARATION

NIC Rev.5.0 implosion initialized at ~20 ns for “handoff”



- *Both* D and T “shocks” are hotter than single-species temperature at same average radius in LSP simulations

Net effect of distinct shock separation on hot spot assembly is under study with LSP